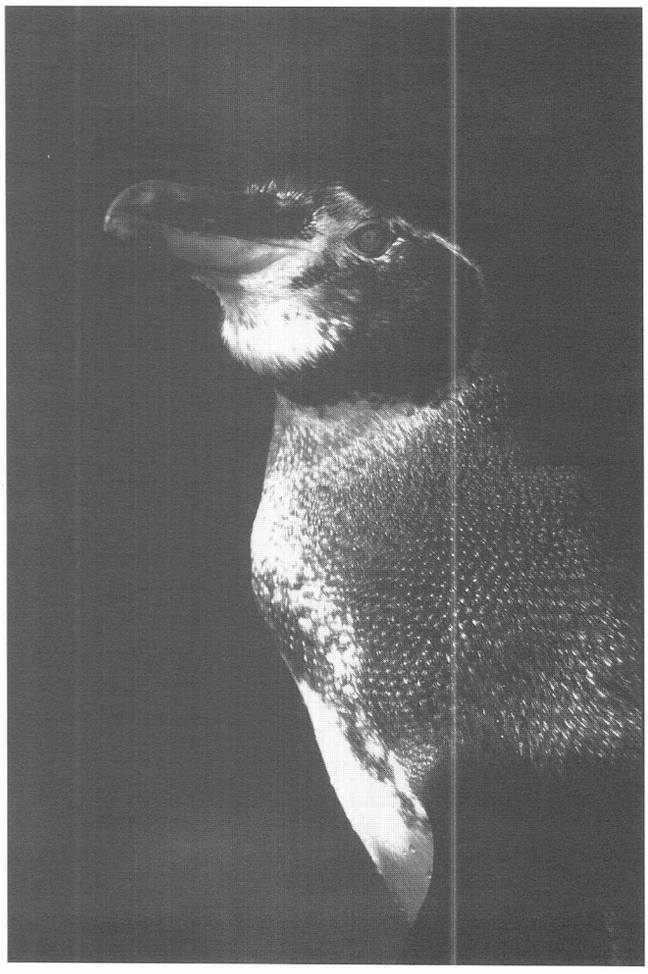
CURRENT STATUS, ANALYSIS OF CENSUS METHODOLOGY, AND CONSERVATION OF THE GALÁPAGOS PENGUIN, *SPHENISCUS MENDICULUS*

By: Kyra L. Mills and Hernán Vargas

INTRODUCTION

The Galápagos penguin, *Spheniscus mendiculus*, is a threatened species endemic to the Galápagos Islands, and one of the least studied penguins in the world. Approximately 90 percent of the population of Galápagos penguins inhabits the two western-most central islands of Fernandina and Isabela, which coincide with the main path of the Cromwell Current. This eastward-flowing undercurrent upwells as it meets the western edge of the archipelago, lowering the surface temperature by several degrees and increasing the productivity in the surrounding waters (Houvenaghel 1978). Since 1970 the population of Galápagos penguins has been monitored via partial and total censuses as a result of the joint efforts of the Charles Darwin Research Station (CDRS) and the Galápagos National Park Service (GNPS). Data from these censuses reveal a fluctuating population that experienced a sharp decline during the El Niño event of 1982-83, and a slow increase since. The intent of this paper is to summarize the results of censuses from 1970 to 1995, and to discuss the methodologies used to estimate the total population of Galápagos penguins. In addition, we present novel data on the expansion of the breeding range of this species of penguin and implications for its preservation.



Galapagos Penguin - Bahía Sullivan, Isla Santiago

There are several factors that contribute to the low reproductive rate of the Galápagos penguin, which may explain the slow recovery from declines caused by events such as an El Niño. Apparently the Galápagos penguin is an opportunistic breeder, breeding when food is plentiful (Boersma 1974). However, once breeding has started the period is long, lasting approximately three months from the incubation of eggs through fledging of young. Furthermore, the mortality of juveniles is high (Boersma 1974). Past censuses indicate that the present population of penguins is still 50 percent smaller than before the 1982-83 El Niño, which caused a 77 percent decline (Valle 1983). Regular monitoring of the population of penguins is of vital importance for the preservation of this species due to its restricted distribution, the effects caused by El Niño events, the threat of introduced animals, and the potential impacts of human activities such as tourism and fishing.

The CDRS and the GNPS are attempting to conduct annual censuses of penguins and to standardize the methods used. Standardized methods for censuses can decrease inconsistencies caused by varying personnel, and/or the timing of censuses. Furthermore, standardized methods facilitate the analysis and monitoring of population trends from one year to the next. A manual that presents methodology for censuses of penguins and flightless cormorants was written in 1989 and has been reviewed and updated in 1993, 1994, and 1995 (Castro *et al.* 1995).

CENSUS METHODOLOGY

Because the flightless cormorant (*Campsohaelius [Nannopterum] harrisi*) and the Galápagos penguin have similar breeding distributions, both species are censused simultaneously. This decreases the time and eliminates the extra costs of conducting a separate census for each species. Even though both species are censused during a

single trip, this paper will mainly focus on the census methodologies for Galápagos penguins.

In conducting a census, several considerations are important, such as the particular behaviors and habits of the species involved, the time of the year, the time of day to conduct the census, and the personnel involved. Each of these factors may introduce error in the results if not planned carefully.

Personnel involved in conducting any of these censuses are two wardens from the GNPS and two scientists from the CDRS. All four people search for penguins both on land and in the water, although one park warden and one scientist are the principal observers. The second park warden is in charge of managing the dinghy, and the second scientist keeps a written record of general weather conditions and the number of penguins counted. The censuses are conducted from a small dinghy, approaching the coast as closely as possible. Counting begins in the early morning, between 5:30 and 5:45, and ends between 17:30 and 18:00, with an hour off at noon. Binoculars (7x25 and 8x40) are used to count penguins that are in the water and on land, and penguins are identified, when possible, as juveniles or adults. The presence of molting penguins is also noted. Atmospheric and oceanographic conditions, including cloud cover, air and sea-surface temperatures and water clarity (measured with a Secchi disc) are recorded from the support vessel at regular intervals.

Despite efforts to standardize counting methods, one of the factors that may contribute to annual variability in efficiency is that each person searches for penguins in a slightly different manner, thereby introducing error when personnel are changed. Annual variations in the apparent numbers of penguins counted often correlate with changes in personnel, and may be due to individual differences and abilities in spotting penguins. During the last three censuses (1993, 1994 and 1995), two individuals participated in two out of the three censuses. Also of great importance is the person who helms the dinghy. Skillful and safe handling of the dinghy combined with knowledge of the census work and the character of the coastline greatly increases the numbers of penguins encountered.

The actual size of a population may be very different from the number of individuals counted in a census. Breeding birds may be more sedentary while actively foraging birds are more conspicuous. Flightless cormorants breed in small colonies on top of the lava. This makes them fairly conspicuous and relatively easy to count. Their breeding activity is also obvious and easily recorded. On the other hand, Galápagos penguins nest in crevices in the lava. This makes them difficult to observe when they are breeding, and the extent of breeding activities is rarely determined during a census. Furthermore, during the times when a census is conducted, most penguins are foraging at sea, and are very easily missed by observers. The most conspicuous penguins are those on land at the water's edge.

Conducting censuses at the same time every year reduces errors caused by comparing reproductive and non-reproductive periods. When Galápagos penguins breed, one member of a breeding pair remains at the nest in the cave during the incubation period and the first few weeks after the chick hatches (Boersma 1974). Those penguins are not observed in a census. Past censuses have occurred during different times of the year, varying from one in January, two in August, two in late August/early September, two in September, two in late September/early October, and three in October. Since 1993, personnel from the CDRS and the GNPS have set the date for the censuses in the period between late August and early September, given that the majority of past censuses were conducted during those two months.

ESTIMATING POPULATION SIZE

Because cormorants are more apparent, a greater percentage of their populations are counted in a census. Thus a census may more directly reflect the actual size of their population compared to a census of penguins. Boersma (1974) attempted to account for this error in estimating the actual size of penguin populations by tagging individuals from two specific populations and then conducting censuses.

She established a method of estimating the total population size of penguins based on those mark-recapture experiments in 1970 and 1971. By comparing the number of banded penguins sighted at two different periods (between January and March, and between June and October 1972), she concluded that penguins counted in a census represent between 10 and 20 percent of the actual number of penguins in the population. She then estimated a total population size between 11,000 and 23,000 penguins in 1971. Using the same method, the range of estimates for the population size in 1983 (the year when the El Niño occurred) is from 2,000 to 4,000 individuals, and that for 1995 (the most recent census) from 4,000 to 8,500.

Currently this method of estimation is questionable because of two potentially important differences in the methods that Boersma used in her analysis and those used recently. Boersma based the maximum and minimum limits of her estimation on counts of penguins done between 15:00 and 18:00, times when the penguins are most likely to be found on land. Current censuses are done between 5:30 and 18:00. Therefore, in addition to the times that Boersma included in her estimates, current censuses cover additional hours when many penguins are at sea foraging (between about 6:00 and 16:30). Thus, recent censuses probably count a lower percentage of the total population of penguins than the 10 to 20 percent documented by Boersma (Vargas 1995*b*).

A second factor that should be taken into account when interpreting estimates of the total population based on Boersma's method, is that her counts of penguins were done in two protected areas, Elizabeth Bay (Isla Isabela)

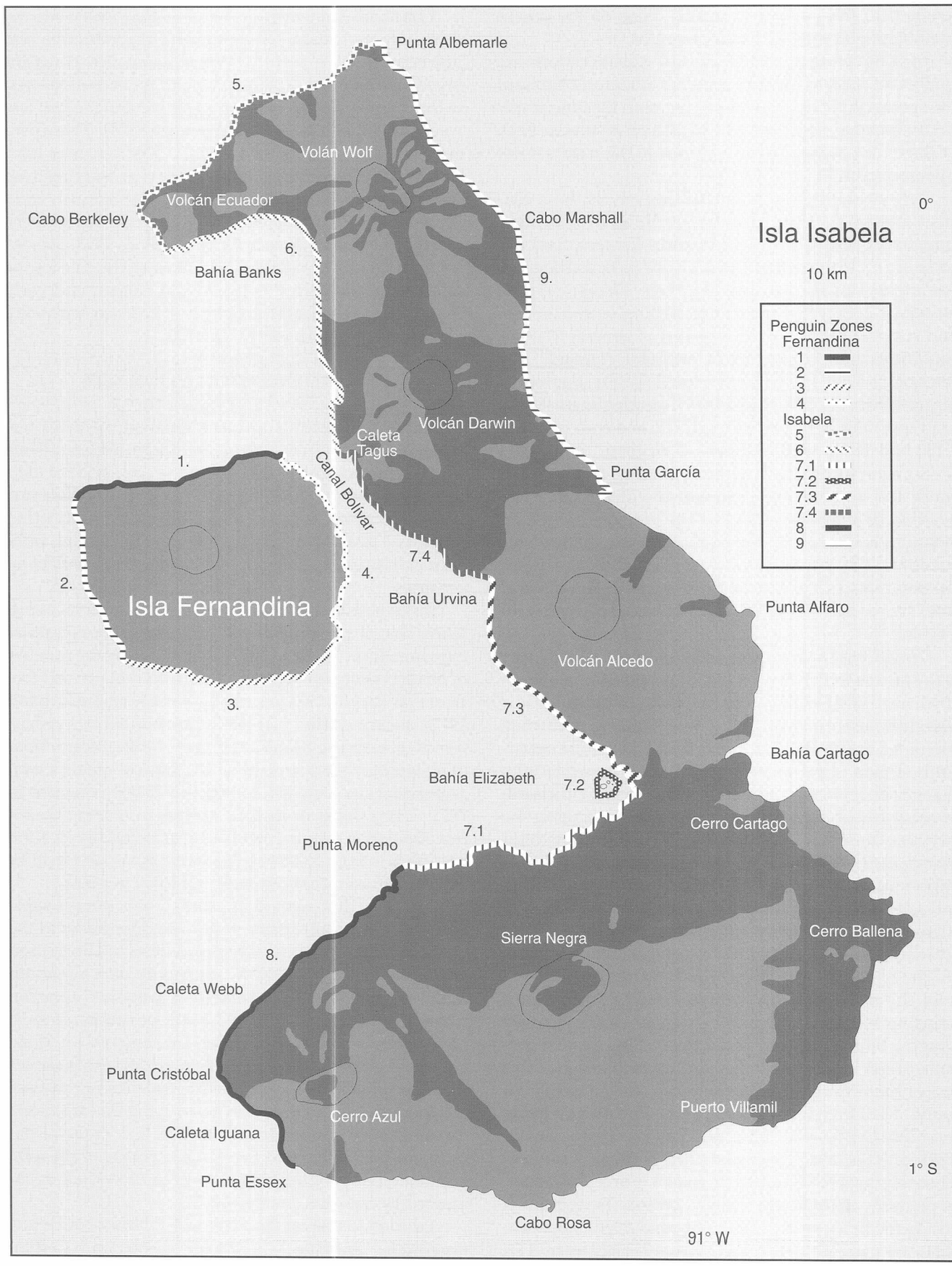


Figure 1. Zones used for dividing the census efforts on Islas Fernandina and Isabela. On Isla Isabela the darker regions indicate relatively barren lava flows. Lava flows are not indicated on Isla Fernandina.

and Punta Espinosa (Isla Fernandina). Current censuses include many areas that are exposed to waves, which make it more difficult to spot penguins both on land and in the water (Vargas 1995*b*). These factors, along with the longer period of the day used for censusing, reduce the success in spotting penguins. Hence, using Boersma's 10 to 20 percent as an index for estimating total population sizes may not be accurate. If current censuses record a lower percentage of actual birds, then using Boersma's indices would under-estimate the total population. To estimate the number of penguins present in the Galápagos more accurately, devising a new set of indices based on multiple censuses of marked individuals will be necessary.

Because limited funds make conducting a total census every year difficult, Rosenberg *et al.* (1990) used analyses of multiple regression to determine the best areas in the archipelago for predicting the total population size. Hence, a partial census could potentially be conducted at a reduced cost, and still be an accurate estimate of the total number of penguins. Islas Isabela and Fernandina were divided into nine zones (Figure 1), which had originally been established by Boersma in 1970-71. Rosenberg *et al.* used data from censuses in 1970 through 1986 to determine which zone or zones were the most reliable predictors, in other words, which zones had the greatest correlation with the total number of penguins observed in a census. They concluded that Zone 7 (on Isla Isabela) was the overall best predictor of the total penguin population, although Zone 1 (on Isla Fernandina) was also a good predictor. Both zones had the greatest abundance of penguins in the censuses. In years when funds are limited, therefore, a census could be conducted in Zone 7, and Zone 1 could be included for more accuracy. Due to the relatively large area that Zone 7 encompasses, Vargas (1995*a*) further divided Zone 7 into four subzones (Figure 1).

RESULTS

To date, 12 total and three partial censuses have been conducted. The first systematic census of this species was carried out in 1970 by P. D. Boersma, who reported a total count of 1584 individuals, and estimated a total population size between 6,000 and 15,000 (Boersma 1974). Further censuses were conducted in 1971 (Boersma 1977), 1980 (Harcourt 1980*a*, 1980*b*), 1983 (Valle 1983), in January 1984 (Valle 1984), in September 1984 (Valle and Coulter 1984), 1985 (Valle 1985), 1986 (Rosenberg and Harcourt 1987), 1989 (Castro 1989), 1993 (Mills 1993), 1994 (Soria *et al.* 1994), and 1995 (Vargas 1995*a*). Partial censuses were carried out in 1988 (Vargas 1988), 1990 (Paton and Valle 1990), and 1991 (Palacios 1991). The most dramatic population fluctuation was recorded in the census of 1983, immediately following the warm-water event known as an El Niño. This census revealed a total count of 398 individuals, or a 77 percent reduction in the population from 1980 (Valle 1983). Population counts since then suggest that the penguin population is still about 50 percent below its original numbers before the El Niño of 1982-83 (Figure 2).

Since the decrease of 77 percent that occurred in 1982-83, a small but steady increase in numbers can be seen, with the 1994 census having the greatest number of penguins in thirteen years (Figure 2). One must keep in mind, however, that there is error between the counts that makes comparing these absolute numbers potentially misleading. Nevertheless, given the similar methodology used in conducting the censuses, the margin of error is possibly small. The two major populations of Islas Isabela and Fernadina are monitored separately because Isla Isabela has introduced predators such as rats, cats, and dogs, which can have serious effects on penguin populations while Isla Fernadina lacks them (Harcourt 1980*b*, Valle 1986, Rosenberg and Harcourt 1987). Isla Isabela had a larger population count before 1980, after which Isla Fernandina had slightly greater numbers until 1993 when, once again, Isla Isabela had a larger population (Figure 2). Variation in the numbers of penguins counted among the census zones appears to reflect the overall pattern of fluctuations at the population level (Table 1).

One indication of a recovering population is an increasing number of young or juveniles observed, indicating successful breeding. Before the 1980 census, adults and juveniles were not counted separately and therefore numbers of juvenile are only known since 1980. Figure 3 shows the percentage of the total population that were juveniles since the 1980 census. Before the 1982-83 El Niño the number of juveniles was low (1.8 percent in 1980), and it remained below 10 percent until 1989. The year that shows the highest reproduction is 1993, with 35.8 percent juveniles. The 1994 census showed a high production (23.6 percent juveniles), although somewhat lower than the previous year, and in 1995 juveniles comprised 17.2 percent of the population.

DISCUSSION

It is not surprising that the censuses of penguins have revealed a slow recovery since the 1982-83 El Niño event, given their high mortality of juveniles, low reproductive rate, and long breeding period. Another limiting factor is a fluctuating food supply, caused by the spatial and temporal variation in the ocean currents that are directly responsible for the availability and abundance of penguins' prey. In addition to these factors, it is possible that human activity may have adverse effects, especially in those areas where it is great.

Contrary to many other species of Galápagos animals, penguins are wary of humans and easily disturbed. Therefore, high levels of tourist and/or fishing activity may pose serious threats to penguins, given their already low numbers. Fortunately, most penguins inhabit the coasts of Islas Fernandina and Isabela, areas where tourism is restricted to a few sites, although illegal fishermen have

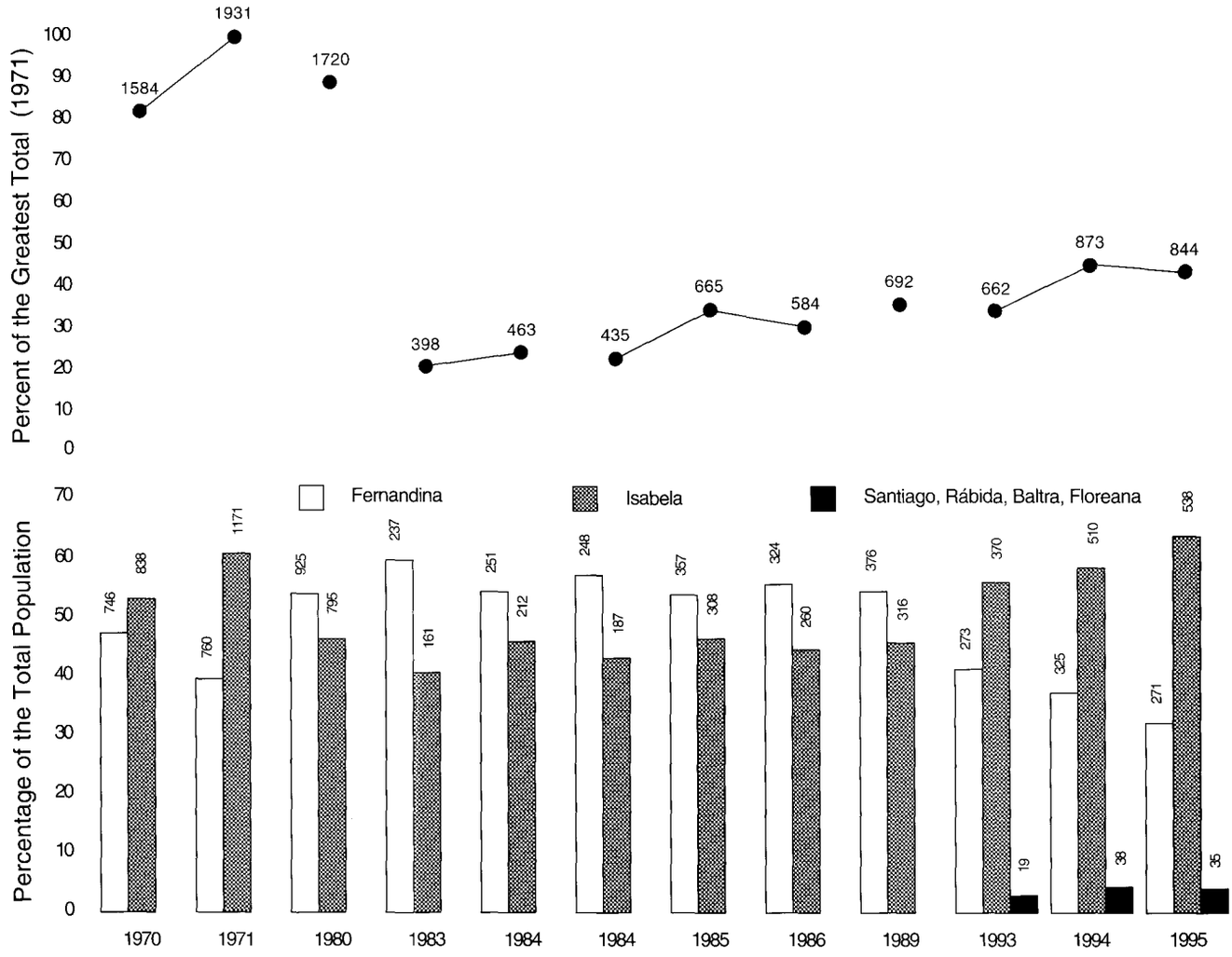


Figure 2. Variation in the numbers of penguins censused. The bars represent the percentages of the total number counted in a year that were found in different areas. The dots represent the totals counted in different years as a percentage of the year with the greatest population (1971). Dots from adjacent years are connected to indicate trends. The numbers above bars and dots are the actual numbers of penguins counted that formed the percentages. Because there are missing years it is important to be cautious in visualizing growth or declines of the population of Galápagos penguins.

been found camping on these remote coasts in recent years. Nevertheless, the most highly visited areas in the archipelago are also areas where small numbers of penguins exist. Even though these populations are small, they may be important for recruitment to the general population (Mills 1994).

Past studies (e. g., Boersma 1974, Harris 1982, and references therein) found the breeding range of the Galápagos penguin restricted to the coasts of the westernmost central islands (Fernandina and Isabela), adjacent to areas where the deep Cromwell Current upwells. Boersma and Harris did not find penguins breeding in the central islands, which are surrounded by warmer waters, although they did report the presence of juveniles and non-breeding adults in several of the central islands and Isla Floreana, a southern island. Recently, breeding was confirmed on Isla Bartolomé in 1993, 1994 and 1995 when chicks were found (Mills 1993, Soria *et al.* 1994, Vargas 1995*a*), and reports from scientists and naturalist guides suggest that breeding may also be occurring on several other islands as well (Isla Floreana [see Vargas *et al.* this issue), Islas Sombrero Chino and Rábida), although there has been no conclusive evidence of breeding found on these islands in the past three censuses. Prior to 1993, the central and southern islands were not included in penguin censuses, but since 1993 the total censuses have been organized to include these islands where the numbers of penguins may be increasing (Figure 2).

Isla Bartolomé is one of the most visited sites in the archipelago and therefore the potential for disturbance of it's population of penguins is great. Small dinghies with groups of tourists approach penguins in the water as well as on land. It appears that these penguins are somewhat accustomed to this level of tourist activity, and allow a

Table 1. Counts of penguins per census zone by year.

Zone[1]	Yearly Total Counted												Average	%
	1970	1971	1980	1983	1984[2]	1984[3]	1985	1986	1989	1993	1994	1995		
Fernandina														
1	41	381	373	86	50	102	134	123	132	92	163	84	147	16
2	36	66	144	11	21	56	41	23	65	40	17	30	46	5
3	83	32	151	73	6	22	17	17	28	32	3	19	40	4
4	586	281	257	67	174	68	165	161	151	109	142	138	192	21
Isabela														
5	75	15	75	5	10	8	18	37	46	35	96	38	38	4
6	144	239	197	45	34	59	38	21	20	36	37	33	75	8
7	568	619	456	93	154	79	232	175	212	212	178	246	269	30
8	51	298	63	18	14	41	20	27	38	87	199	220	90	10
9	0	0	4	0	0	0	0	0	0	0	0	1	0.42	0.05
Others														
10	NA	NA	NA	NA	NA	NA	NA	NA	NA	19	38	35	31	3
TOTAL	**1584**	**1931**	**1720**	**398**	**463**	**435**	**665**	**584**	**692**	**662**	**873**	**844**	**904**	

[1] See Figure 1 for definition of zones.
[2] This 1984 census was in January
[3] This 1984 census was in September.

closer approach than penguins do on Isla Fernandina or Isla Isabela. However, many penguins on Isla Bartolomé show signs of being disturbed because they enter the water upon approach, or they swim away, if already in the water (Mills, personal observation). Even though GNPS regulations prohibit chasing or touching the animals, these rules are not always respected. At the moment, there is no restriction on how close tourists can approach penguins. In the past, the potential disturbance of penguins caused by visitation on the central islands was not considered detrimental to the population because it was believed that these penguins were immature and therefore non-breeders. However, because breeding penguins are more easily disturbed, and we now know that penguins are breeding in the central islands, new tourist regulations may need to be applied in these areas.

Introduced animals may pose serious threats to the population of penguins on islands such as Isla Isabela. The potentially most damaging introduced animals appear to be rats, cats and dogs, which can eat penguin eggs, juveniles, or adults. Because these introduced animals pose serious threats to penguins and other endemic species, the CDRS and GNPS hope to control their populations. Nevertheless, funding for these programs is scarce and eradication is difficult on some of the larger islands. However, localized control of populations of introduced animals is feasible, and could be implemented in areas that have the highest densities of breeding penguins and cormorants. Of particular concern in the past few years has been the possibility of introducing alien animals to Isla Fernandina, the largest remaining island in the archipelago with no introduced vertebrates. Because of the recent illegal fishing camps on this island, the likelihood for the introduction of animals has increased, although so far there has been no confirmation of any introductions. Because Isla Fernandina has high densities of breeding flightless cormorants and Galápagos penguins, the introduction of animals such as rats, cats, or dogs would be devastating to these endemic seabirds. In addition, human disturbances such as fishing offshore and camping

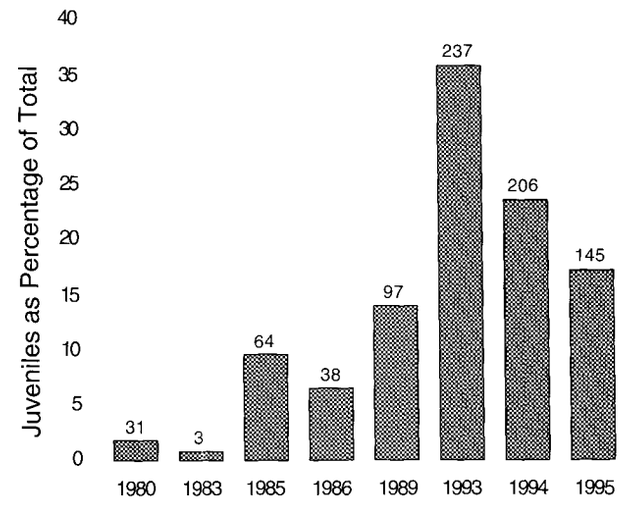


Figure 3. The population of juveniles as a percentage of the total population. The bars represent percentages and the numbers above the bars are the numbers of juveniles counted.

could have contributed to the decline in numbers of penguins that has been observed on Isla Fernandina since 1993.

Since the 1982-83 El Niño there have been six El Niño events of weaker intensity. The 1982-83 El Niño appears to be one of the most severe ever observed (Barber and Chávez 1986). El Niño events in Galápagos are characterized by increases in sea-surface temperatures and the suppression of marine primary productivity (phytoplankton). This decrease in primary productivity creates a cascade effect on the higher trophic levels, including the top level of marine mammals and seabirds (Barber and Chávez 1983, Cane 1983). Hence, in El Niño years there is a reduction in the availability of prey for penguins. Now that penguins are known to be breeding on the central islands and because El Niño events may be more frequent, the small, central island populations may be crucial for the maintenance of penguins in Galápagos.

Results from recent censuses have given us a reason to be optimistic about the recovery of the population of Galápagos penguins. The high percentage of juveniles and the highest numbers of birds counted since the dramatic decline following the 1982-83 El Niño, suggest that the penguin population is recovering, although slowly. As with any other population of animals, there will always be natural fluctuations in the numbers of Galápagos penguins, but it is within our capacity to diminish the negative effects of human activity. When natural fluctuations caused by events such as an El Niño are combined with fluctuations caused by human activity, the results can be devastating. Therefore, if we are successful in eliminating the negative human effects, then this rare species of penguin will have a better chance at survival. The regular monitoring of these populations through annual censuses will foster the early observation of potential declines.

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MONOECY IN THE DIOECIOUS *CROTON SCOULERI*, ENDEMIC TO GALÁPAGOS

By: André Mauchamp

INTRODUCTION

Establishment on islands is a challenge for propagules arriving with the winds, the marine currents or borne by animals. Survival capacities of the first individual plants determine their fate in the short term. Whether they can form a viable population depends on a complex array of traits, among which are the characteristics of the breeding system. It is generally considered that hermaphroditic self-compatible species have a better chance to establish on an island, since a single propagule can be sufficient to build up a population (Baker 1955). On the other hand, this may lead to low genetic variability, possibly negative in the long term. The contrasting proportions of different breeding systems on islands, about twenty percent dioecious in Hawaii and New Zealand (Bawa 1982) to less than three percent in Galápagos (Baker and Cox 1984), shows that a complex array of selective pressures determine the reproductive traits of plants on islands. These observations led to a considerable interest in the evolution of breeding systems, particularly on islands (Baker 1955, Carlquist 1966, Bawa 1980, 1982, Givnish 1982, Baker and Cox 1984).

Studies of the flora of the Galápagos Islands started with the very first scientific journeys to the archipelago (Hooker 1847, Stewart 1902) and culminated with the publication of the *Flora of the Galápagos Islands* (Wiggins and Porter 1971). However, relatively few studies focused on the processes of population dynamics or the reproductive biology of the Galápagos plants. The main studies of breeding systems show that self-compatibility is highly represented in the islands (Rick 1966; Grant and Grant 1981; and McMullen 1985, 1986, 1987). The dioecious species were described in Wiggins and Porter (1971) but never specifically studied. I present three cases of "leakage" in the breeding system of the dioecious *Croton* on three of the Galápagos islands.

THE SPECIES

Croton scouleri Hook f. (Euphorbiaceae) is an endemic species of the Galápagos Archipelago. It is a highly variable taxa usually divided into four varieties, *brevifolius* Muell Arg., *darwinii* Webster, *grandifolius* Muell Arg. and *scouleri*, according to the size of the leaves and a few other morphological traits (Wiggins and Porter 1971, Lawesson *et al.* 1987). It is present on most of the islands of the archipelago (45 of a sample of 77 islands, Snell *et al.* 1995). Species of the genus *Croton* are dioecious or monoecious (Mabberley 1987). *Croton scouleri* was considered exclusively dioecious (Wiggins and Porter 1971). However, monoecy was recently observed in a few specimens by C. Huttel on Isla Española and nearby islets.

RESULTS AND DISCUSSION

Monoecy was observed in three areas. Charles Huttel collected monoecious specimens in the southern archipelago: on Isla Osborn (specimen Huttel # 2283), Isla Gardner (Huttel # 2290) and on Isla Española (Huttel # 2440). One monoecious population was found on Isla Isabela, on the southeastern slope of Volcán Alcedo, about 850 m elevation, and another on southern Isla Genovesa, a low, dry island in the north of the archipelago. The pattern was the same for all three populations. Three types of plants could be found: female trees with only female inflorescences of ten to thirty flowers; male trees that bear male inflorescences with a similar number of